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Emissions of biogenic VOC from forest ecosystems in central Europe: Estimation and comparison with anthropogenic emission inventory

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The amount of the biogenic VOCs emitted over the central Europe is comparable with the anthropogenic VOC emissions from this region.

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ABSTRACT

This paper describes a method of estimating emission fluxes of biogenic volatile organic compounds (BVOCs) based on the approach proposed by Guenther et al. (1995) and the high-resolution Corine land-cover 2000 database (1×1 km resolution). The computed emission fluxes for the Czech Republic (selected for analysis as being representative of a heavily cultivated, central European country) are compared with anthropogenic emissions, both for the entire country and for individual administrative regions. In some regions, BVOC emissions are as high as anthropogenic emissions; however, in most regions the BVOC emissions are approximately 50% of the anthropogenic emissions. The yearly course of BVOC emissions (represented by monoterpenes and isoprene) is presented, along with the spatial distribution of annual mean values. Differences in emission distributions during winter (January) and summer (June) are also considered.

1. Introduction

Large quantities of volatile organic compounds (VOCs) are emitted into the atmosphere from natural sources such as the oceans and freshwater bodies, soil and sediments, and the microbiological decomposition of organic material. The most important emitter is vegetation, especially forest ecosystems (Guenther et al., 1995). Biogenic VOC (BVOC) are a relatively large group, including isoprene, terpenes, and a number of oxygenated compounds (Seinfeld and Pandis, 1998); however, previous emission-inventory studies reveal that the species emitted from vegetation in the highest concentrations are isoprene (C_5H_8) and monoterpenes ($C_{10}H_{16}$) (e.g., Atkinson and Arey, 2003).

The function and mechanism of VOC production in plants are being widely studied. A great progress has been achieved in understanding the pathways of isoprenoid formation in plants (Kreuzwieser et al., 2008). Their ecophysiological functionality is still in many cases uncertain; however, several studies have proven that plants emit monoterpenes to defend themselves against pathogens, parasites, or herbivores (Holopainen, 2004), other investigations suggest that isoprene formation within plant foliage may serve to prevent light or heat damage (Singaas et al., 1997).

The concentration of BVOCs in the atmosphere ranges from several ppt to several ppb, and the chemical lifetime of such compounds ranges from minutes to hours (Kesselmeier and Staudt, 1999), indicating high reactivity and therefore their importance in controlling the chemical capacity of the atmosphere. When reacting with the hydroxyl radical (OH), nitrogen oxides (NO_x), and ozone (O_3), VOCs play a significant role in the photochemistry of the atmosphere, as they influence the concentrations of low-level ozone (Fiala and Zavodsky, 2003). An additional consequence of interaction between VOCs and ambient air is the formation of secondary aerosol particles, a component of PM_{10} (Larsen et al., 2000). Both ozone and PM_{10} are known to have a negative effect on human health (e.g., Dockery et al., 1993; Lippmann, 1989) and on vegetation (e.g., Karnosky et al., 2007).

Emissions of BVOCs from vegetation vary with plant species, plant conditions (e.g., developmental stage, occurrence of injury or damage), and plant environment. Biogenic emissions show significant temporal and spatial variations arising from their dependence on geographical position and environmental factors, mainly ambient temperature, light intensity, and air pollution (Kesselmeier and Staudt, 1999). Guenther et al. (1993) demonstrated that emissions of isoprene increase linearly with increasing photosynthetically active radiation (PAR) until saturation at higher values of PAR, and increase exponentially with increasing leaf temperature to a maximum of around 35 °C, thereafter decreasing due to inactivation of the isoprene-forming enzyme. Whereas isoprene volatilization from vegetation appears to be controlled by temperature

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and light, monoterpene emissions appear to depend mainly on temperature.

Given the important role of BVOCs in determining atmospheric chemistry, it is essential to accurately estimate their concentrations for the atmospheric photochemical modeling purposes. Compared with anthropogenic VOC emissions, the contribution by natural sources is likely to be extensive; however, estimates of biogenic emissions involve large uncertainties. For example, Simpson et al. (1995) estimated that the uncertainty in their estimates of emissions for areas of Europe could be as high as a factor of 5. These uncertainties are thought to be the greatest during the beginning and end of the growing season (Guenther, 1997), and largely arise from inaccuracies in plant emission factors and insufficient ecosystem description in the model domain.

Figs. 1 and 2 demonstrate the importance of BVOC emissions in the formation and distribution of tropospheric ozone concentration. Fig. 1 shows the modeled distribution of monthly mean O_3 concentrations in September 2000 throughout the Czech Republic, without taking BVOC emissions into account. This result was achieved using puff model *SMOG* (see Bednar et al., 2001). Fig. 2 shows the measured distribution of ground-level ozone for the same month, for which BVOC emissions are obviously taken into account. The O_3 distribution shown in Fig. 2 was reconstructed from data provided by all the available monitoring stations in the Czech Republic, using GIS software. It is possible that the contribution of anthropogenic activity (e.g., plumes arising from urban areas) is underestimated in Fig. 2, but the impact of BVOCs on ozone creation is not captured in the map shown in Fig. 1. Great differences in ground ozone concentration values when comparing Figs. 1 and 2 also come from the fact that a constant value for background ozone level (transport from abroad, BVOC emissions, unidentified VOC and NO_x sources etc.) was used in the whole model domain. This value was estimated to be equal to 80 $\mu g\,m^{-3}$ which now seems too high. The *SMOG* model was used for estimation of mean daily values (12 h averages from 6am to 6pm). These results and their comparison with data shown in Fig. 2 were presented for illustration of BVOC importance. The Czech Republic was chosen as a study area because of the large amount of available data, and because it can be viewed as representative of a central European country with a heavily cultivated landscape.

The following section describes the methodologies employed in estimating BVOC concentrations and application of the method. The Results and Discussion section presents the estimated temporal and spatial distribution of BVOC emissions from forest ecosystems, which are then discussed and compared with the inventory of the anthropogenic VOC sources.

2. Methodology

A crucial factor in the accurate estimation of VOC emissions from natural sources is the description of ecosystem coverage in the model domain. In this study, we used the Corine land-cover 2000 database (EEA, 2007) with a 1×1 km grid. Because tree species are the main emitters of BVOCs, only forest land-cover categories (i.e., deciduous, coniferous, and mixed forest) were taken into account. To assign a suitable emission factor for each chemical compound and each land-cover category, it was desirable to obtain information regarding the composition of tree species in each ecosystem. Accordingly, we obtained data regarding the main forest constituents in each of fourteen regions (see Fig. 3) within the Czech Republic from the database of the Forest Management Institute, Brandys nad Labem.

We applied the model of biogenic VOC emissions proposed by Guenther et al. (1995) following further revisions by Guenther (1997). The emission flux E_{ij} ($\mu g\,h^{-1}$) of the chemical compound i from ecosystem j consisting of the number of tree species k is calculated as

$$E_{ij} = A_j\Big(\sum_k f_{jk}\cdot\varepsilon_{ik}\cdot D_k\Big)\gamma_i \qquad (1)$$

where A is the area covered by the emitting ecosystem (m^2), f is the proportion of the area within the given land-cover category covered by the given tree species, ϵ is the emission factor for a given tree species ($\mu g\,m^{-2}\,h^{-1}$; i.e., the emission of a compound under standardized conditions consisting of a PAR flux equal to 1000 $\mu mol\,m^{-2}\,s^{-1}$ and leaf temperature of 30 °C), D is foliar density (g dry leaf matter m^{-2}), and γ is a dimensionless correction factor that accounts for the influence of solar radiation and leaf temperature. The emission factor ε and foliar density D are dependent on the ecosystem, whereas the correction factor γ depends solely on environmental conditions. The fraction of tree species f varies with ecosystem location in the domain area.

In the case of isoprene, the correction factor γ is the product of two coefficients: C_T (temperature dependence) and C_L (sunlight dependence). Unlike the original formula, in this study we use an approximation of leaf temperature by ambient air temperature.

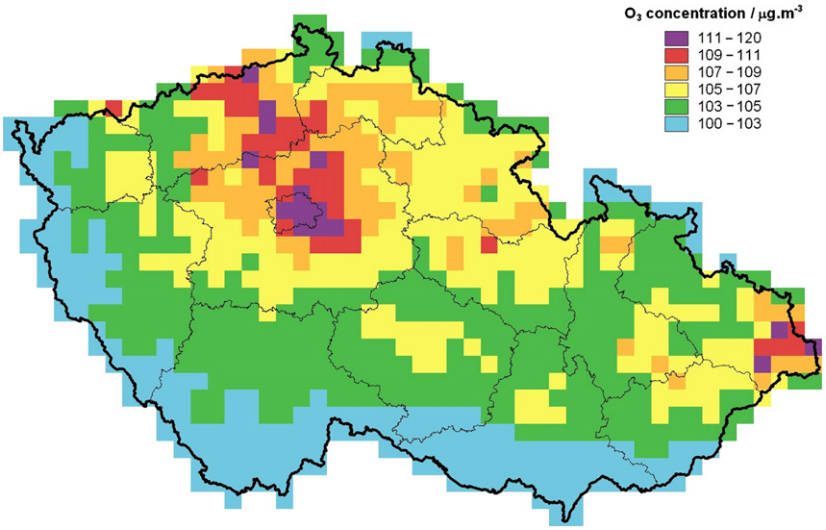

Fig. 1. Model predictions (anthropogenic emissions only) of monthly mean ground O_3 concentrations for the Czech Republic for September 2001.